Structured Systems Evolution:
Employing dynamic, executable architectures

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Abstract

To enhance systems migration planning, including acquisition, implementation, and integration, an approach that injects executable enterprise information technology (IT) architectures into the Department of Defense (DoD) planning and budgeting processes is required. Such an approach is proffered in light of the overarching issue and debate concerning the use and benefit of generating and implementing architectures.

The best features of several architectural frameworks are woven into the approach discussed here. Among those frameworks are the John Zachman and Steven Spewak concepts and the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) strategy grounded in the Air Force Horizon, Navy Copernicus, and Army Enterprise architecture methodologies. Basic to these architectural approaches is the development of an enterprise business model, the identification of the tasks and activities performed within the organization.

The approach takes the information systems developer from operational requirements (reflected in the operational architecture) to the systems infrastructure (illustrated in the systems architecture) to systems evolution (outlined in the migration plan). By generating both “As-Is” and To-Be” architectures it is possible to create a roadmap or migration plan from the current information environment to a future “end state” or objective. The construction of these architectures or blueprints is best accomplished in an “architecture studio.”

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1.0 Introduction

This paper addresses the commonly asked question, "Why do architectures, what good are they?" The answer to the question is to develop dynamic, executable architectures that permit operations improvements supported by modeling, analyses, and 'what-if' gaming studies. To accomplish these goals, architectures must become an active player in the Modernization Planning Process (MPP) and the Planning Programming and Budgeting System (PPBS). Architectures must therefore provide information that will improve the effectiveness of both processes. This paper discusses how architectures should be developed and employed in a way that will enhance an improved migration of systems and capabilities to fulfill the visions and needs of the 21st century defense community.

Starting with the very basics, there are numerous definitions and concepts of the word 'architecture.' Once mentioned, 'architecture' conjures up numerous visions and carries a great deal of excess baggage. Two definitions will be used in this paper as adopted by the DoD C4ISR Architecture Framework. Both are similar, in that they seek to define the relationships and substance of an entity or group of entities and how the relationships between both should evolve to attain a goal or set of objectives:

> "A framework or structure that portrays relationships among all the elements of the subject force, system, or activity" - DoD Joint Pub 1-02

> "The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time" - IEEE Standard 610.12

Architectures, if done well, synthesize the visions, strategies, requirements, and capabilities needed for sound information technology (IT) investments, timely technology insertion, and mission capability sustainment. Architectures also provide vital activity to system functional traceability, process reengineering, and information systems definition and planning. This is particularly important, in light of recent legislation such as the Information Technology Management reform Act (ITMRA) and the Government Performance and Results Act (GPRA). These laws require DoD organizations to measure the performance of existing systems and the return on investment for planned systems and to report these statistics on an annual basis.

The overall relationship between the Air Force's IT architectural development process and the DOD PPBS is illustrated in Figure 1. The graphic shows the interrelationship among the various types of architectures and their eventual input to the actual systems acquisition. The architectures also inject operational needs, systems requirements, and technical guidance into the Modernization Planning Process documentation. This documentation, in turn, should function as some of the driving forces behind the mission need statements in the Mission Area Plans. The operational requirements then flow into the newly established Annual Planning and Programming Guidance (APPG) which directs the generation of the Air Force POM as part of the PPBS, the cyclic process that produces the DOD portion of the President's Budget (PB) submission to Congress. The approved budget subsequently permits acquisition of needed new or modified systems [Riha *et al*., 1998].

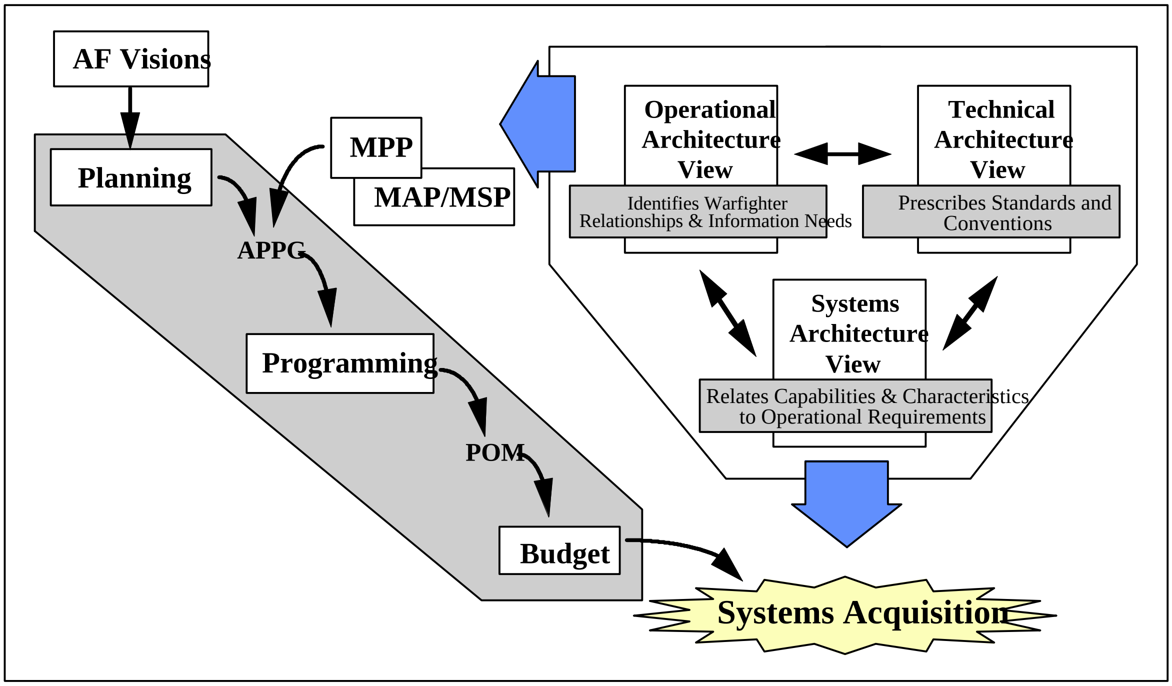

Figure 1 - The Architecture/PPBS Relationship [Riha *et al*., 1998].

Underlying this issue are the problems of how better to identify operational requirements for information systems and the insertion of emerging information technology into the existing infrastructure of an Air Force organization. Along with this problem is the issue of how to determine gaps, disconnects, or shortfalls in the current operations and systems infrastructure and capture them in the MPP via Mission Area Plans and Mission Support Plans as 'strategies-to-tasks' and 'deficiencies.' How architects, planners, and developers envision the future or "to-be" operational/systems environment, and subsequently develop a systems evolution strategy and/or plan to achieve it is critical to success.

This paper delineates a methodology that incorporates operational, systems, and technical architectures (as mandated in the C4ISR Architecture Framework) to facilitate convergence toward compatible information systems, accessible information in a shared data environment, compatible databases and applications, and compatible operating procedures. The role that C4ISR Architecture views play is important. The operational architecture is developed to determine the operational requirements for mission connectivity between functional elements in order to accomplish the military mission(s). The systems architecture is then established to identify the appropriate information, communications infrastructure, and systems needed to actuate and fulfill the operational requirements. The technical architecture - in the form of standards, guidelines, and technical reference codes and models - provides the control mechanism to guide systems toward an interoperable configuration.

Being based upon the operational architecture, the entire approach is built upon the enterprise business model, the delineation of the functions, tasks, and activities of the organization. This is

accomplished by first developing an in-depth business model of the enterprise's mission activities. In conjunction with the business model, a catalog or database of the existing systems, applications, and functions that are used to perform these activities is populated. The products of the C4ISR Operational Architecture are generated, providing an "As-Is" depiction of the existing information exchanges, operational elements, and supporting infrastructure.

Operational products are mapped to the Systems Architecture, identifying system-to-system interoperability and related information needlines between the operational elements. By generating both "As-Is" and To-Be" architectures it is possible to create a roadmap or migration plan from the current information environment to a future "end state" or objective. The use of System Migration Charts are key during this phase of the process.

This architecture development is for naught if the results and products simply become "shelf-ware" and are not actively employed in the systems acquisition process. Here lies the key to improving C4ISR systems acquisition. Having generated both operational and systems architectures, in both an "As-Is" and "To-Be" perspective, these architectures are integral to the MPP- especially if they reside in a web-based environment where data can be updated, manipulated, and extracted easily.. Besides operational requirements and systems configurations, the architectures provide products which define baseline capabilities, concepts of operations, operational deficiencies, improvement concepts, mission objectives and tasks, and other supporting data vital to the MPP.

The MPP, in turn, is infinitely tied to the DoD PPBS through the generation of the Program Objective Memorandum and President's Budget. The relationship and interdependence, however, does not stop there. During systems acquisition and implementation, the architectures should be used to direct systems integration by identifying implementation concepts between existing legacy and newly acquired systems and/or between evolving capabilities. Eventually, the new systems become part of the new "As-Is" infrastructure and the process repeats itself, in a continuous spiral of technology insertion and systems applications.

Just as Frank Lloyd Wright brought his budding architects together at Talisien and Oak Hill, a parallel concept of an "Architecture Studio" for the development of information technology (IT) blueprints is addressed in this paper. The collection of architecture generation tools in a software laboratory or Architecture Studio where business modeling, C4ISR product generation, and other engineering analyses can be accomplished should lead to better integratable architecture products immediately useable by the systems acquisition community.

In this approach, particular attention is devoted to C4I issues management, identification of operational requirements, and the systems integration strategy. The paper describes the steps of this approach in detail and illustrates its cyclic nature. The inevitable relationships between architectures, planning, budgeting, and acquisition are presented. In conclusion, whereas, parts of the approach are being used today- this approach, in its entirety, is not fully ingrained into DoD processes. The approach is intended to represent a complete package encompassing operational and systems architectures, the Modernization Planning Process, and the Planning Programming and Budget System.

2.0 The Process

Architectures are the guideline for the process of developing, maintaining, and evolving the force structure. If done well, the product is interoperable information systems and integratable forces. The operational architecture is the key to the entire process because it is the place where military visions are converted to capability requirements that can be acted upon by the systems and technical architecture planners and engineers. If the process does not start with the operational architecture there is the risk that the operational visions of the warfighter will not be optimally realized [Beamer and Beckner, 1997].

The system architecture is where operational visions and requirements merge with technology and standards to become hardware and software reality. Critically important to this process is constructing the system architecture on an integrated information base that will support common systems and foster information superiority across US forces and their multinational allies.

The technical architecture role in the above process must not be ignored. The warfighters visions and needs, as defined in the operational architecture, become state-of-the-art capabilities in the systems architecture. They leverage on the research, modeling, testing, and standardization of products derived through technical architecture activities.

The three architecture views must be integrated together to optimize the military force modernization planning effort. Without the operational architecture to represent the capability needs of the systems “owner”, the technical architecture “designer” cannot work with full success with the “builder” of capabilities through a systems architecture development and evolution plan and implementation strategy. If any of the three legs of the architecture structure are weak, the entire modernization planning process will be weak. If the operational architecture is absent, then assumptions on what the owner needs and wants will be made by the designer and developer. In the past this situation has lead to a disappointed owner-operator, and a less than optimal force capability [Beckner and Norman, 1998].

Modernization planning in the US military environment starts at the top with National Policy, Service Missions, DOD Strategies, Leadership Visions and Command Initiatives. Typically this level of planning is general in scope and goal oriented. The vectors thus generated are usually turned over to specific commands within the services to submit for funding through the Program Objective Memorandum (POM), program, budget, and convert the visions, concepts, and operational concepts and goals into military realities and National potential [AFPD 10-14].

The core modernization process is complex as can be seen in Figure 2. Implementation requires an ordered and fully orchestrated set of events that encompass the vision, planning, acquisition, budgeting, experiments, battle laboratory training and sustainment activities of an organization or command. Although the final product of the modernization process is the Mission Area Plan (MAP), documents that should govern and guide the entire process are the architectures.

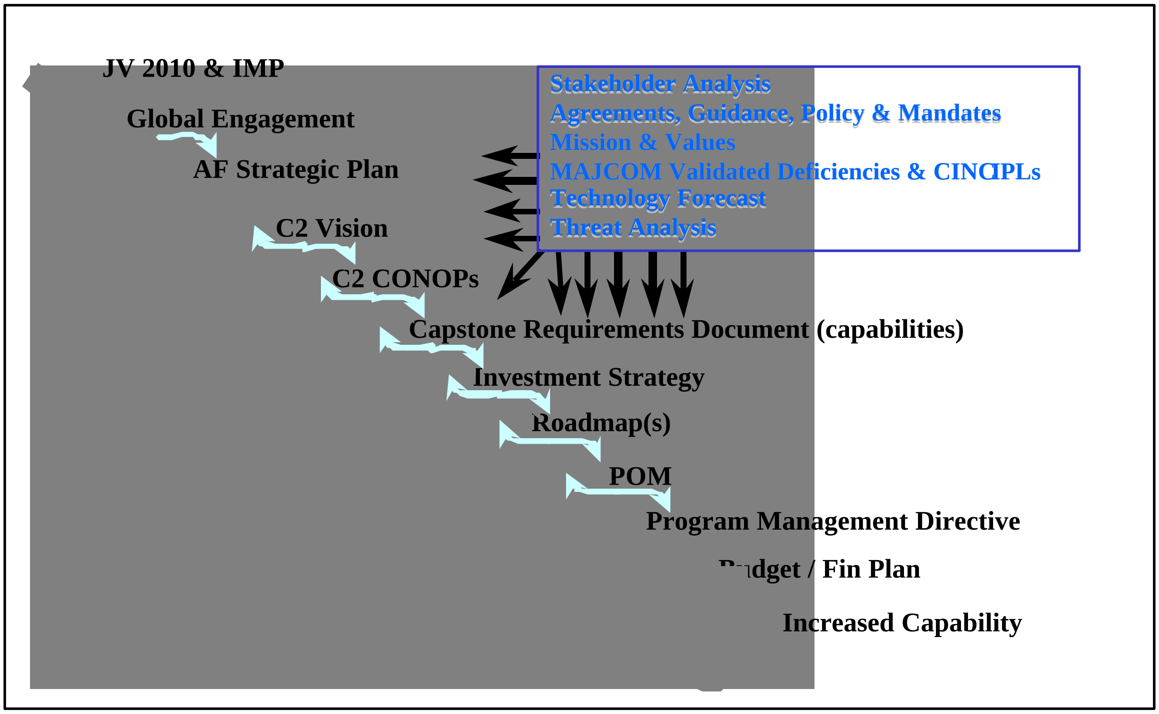

Figure 2. Core Modernization Process

The actual evolution of systems from the current “as is” architecture configuration to the desired future “to be” state requires engineering skill and administrative cooperation. The engineering skill activities are centered on evolving systems and capabilities, often under fiscal constraints, from the “as is” configuration to the “to be” configuration without lapses in operational readiness, availability, and connectivity. The “to be” systems architect should orchestrate this process, and at the same time, champion the cause for funding, testing, and fielding the increments as they are delivered. If funding shortfalls occur, or delivery schedules slip, the architect must adjust the evolution plan accordingly to avoid, or at least minimize, the impact on operational elements of the force.

3.0 Business Modeling

Business modeling is the process of defining the business activities. The purpose of the business model is to provide a complete, comprehensive, consistent knowledge base that can be used to define the architectural views, implementation plans, and migration strategies. The preliminary business model identifies the operational functions, provides a brief description of each function, and determines the organization unit that performs each function. The flow of information between functions is also captured.

The initial task is to document the structure of the organization and identify the individuals or nodes and their locations that perform the business functions. The key is to chart the inherent structure of the organization and to identify the organizational units that must communicate in

order to accomplish the organization's mission(s). This information can be obtained through structured interviews and review of organization charts, telephone directories, budgets, and other organizational documents.

Next, the actual business of the organization is identified by the determination of the tasks or functions performed by the units or nodes of the organization. A function is any set of actions performed in the course of conducting business [Spewak, 1992]. Delineating the functions is essential before defining the operational and systems architectures. Organizational activities are collected until no further functional decomposition to greater levels of detail is possible.

During later stages of architecture development, while building the operational and systems views, the architect and business activity owner will determine who performs the functions. Also, how those functions are performed, where and when it is accomplished, the priority of the functions, the technologies and resources employed, and of most importance, the determination of the data flows, information needlines, and other interfaces must be documented. Having related the functions to the organizational elements that perform the functions, the architectural products as outlined in the DoD C4ISR Framework can now be generated.

It all starts with the business model. The business model feeds the operational architecture which, additionally, is predicated upon the concept of operations. In turn, the systems architecture and systems migration strategies are based upon the organization's operations.

4.0 Architecting

Architectures provide a mechanism for understanding and managing complexity [Zachman, 1997]. Well-developed architectures improve capabilities by enabling the quick conversion of well-defined requirements into sound investments that are time-phased to meet operational needs. The current challenge is to implement a methodology that will facilitate the development and use of architecture products in a way that will be cost effective, interactive, and timely. The solution is to maximize the use of information technology in a comprehensive planning environment. The vehicle is an Advanced Planning Architecture Studio, or simply, the Architecture Studio.

The architecture studio concept embraces the idea of providing a workplace for the architect. As with any good work environment, the studio should have the hardware, software, and connectivity needed to do the job quickly and efficiently. Depending on the scope of the architecture, the architects' studio could be a workstation at a desk, or a series of workstations in a room or facility that is configured specifically for architectural work. The former situation might be appropriate for a small organization. The latter might work best for a large organization that would focus more on a team construct where recognized best practices are used with recognized tools to achieve design and development goals consistent with the common architecture picture view of any domain or set of domains.

An effective architecture studio should include an architecture development library. This library should be centered around an on-line system that has access and web connectivity to architecture development references such as the C4ISR Architecture Framework, software tools, and other

information appropriate to the architecture development effort. The architecture library can also be the repository for the architecture products as they are developed. An enterprise-wide architecture development library could be the repository for multiple, related architectures which could share common products such as the data dictionary.

The architecture studio could be configured for multiple uses. One use might be as an environment where OPLAN and network planning development activities could have direct access and interface with architects and system developers. Another use might be for modeling and simulation of systems and capabilities needed to satisfy deployment and employment needs on a near real-time basis. The architecture studio should be *the operations center for current and future planning*. The ultimate architecture studio and OPLAN development "facility" would exist in a collaborative virtual workspace environment [Beckner and Norman, 1998].

The supervisor of the Architecture Studio should be the architect. The architect is the person charge of the architecture and those working to define, refine, and maintain the architecture products and database. The role and skills of the architect should not be confused with that of the engineer. Although the architect may be an engineer, the engineer and architect require different types of skills and perspectives to perform their specific and distinct duties. The activities of the architect and engineer(s) are summarized in Table 1. As can be seen, the architect and the engineer(s) must work together, supplementing the other's knowledge and both understanding the goals and constraints needed for the architecture to be successful [LaCroix, 1998].

Development Activities	Engineer	Architect
Active realm	Technical	Political & Technical
Focus	Quantitative	Qualitative & Quantitative
Uses	Analytic Tools	Knowledge & Experience
Applies	Physical Science	Inductive Reasoning
Derives	Specific Solutions	Broad Guidelines
Assesses	Cost	Operational Worth
Responds to	Architect/Client	Client
Concerned with	System Components	Inter-Relationships
Knowledge Base	Specialty Depth	User Environment
Objective	Technical Elegance	Military Utility
Primary Discipline	Science	Art and Science
Delivery Goal	Built to Specifications	Certified for Use

Table 1. Engineer and Architect Activities

Ultimately the architect is responsible for the physical and conceptual integrity of the capability as seen by the client, builder, and all the stakeholders. *The role of the architect is not trivial.* It should not be delegated to individuals or organizations with average experience or skills.

It is important for the architect to be able to calculate the approximate cost of developing and maintaining the architecture and its products. Knowing approximately what the cost can be will assist in budgeting for the effort, which in turn will help insure that the products are sustained in current and useable form over their lifetime. Tables have been formulated to help determine the cost of developing architectures and their products [Beckner and Norman, 1998]. These tables estimate the cost of staffing the architecture task focusing on effort versus dollar, and identify the basic hardware and software that the architecture team may need to do the work. Overhead and life cycle costs can be extrapolated from these basic tables.

An architecture staffing matrix can also be used to estimate the number of staff years needed to develop and sustain each architectural product. The military, Civil Service, or contractor grade range of the individual that would be expected to do the task is indicated in the matrix. The matrix presumes that the persons assigned to the architecture development task are qualified for the task in accordance with the criteria established by the architect. The key factors to consider are contractors' corporate knowledge, architecture development experience, and access to the current and future information needed to produce non-proprietary architecture views and products.

Objective	**Activity Overview**	**Tasks**	**Staffing**		**Annual Cost**
			Grade	**Quantity**	
<u>**Administer Program**</u>	• Determine architecture type(s) (Operational, Systems, Technical) to be developed. • Scope Architecture (Time/Phase of interest, geographical/ organizational limits) • Define Process (Top Down, Bottom Up, Current and/or Future) • Define minimum set of products # and publishing media (paper or website) • Cost & Schedule	• Supervisor/Architect - Define Process and regulate costs - Obtain Content OPRs - Define and deliver architecture/products - Complete AV-1* • Administrative Asst. • Webmaster (if applicable)	05/GS13 E-7 E-5	1.0 0.4 0.3	$59K $11K $ 6K
(Estimated) Number of Staff Years Required				1.7	
(Estimated) Annual Labor Cost of Overhead					$76K

* Essential C4ISR Architecture Product

\# The minimum set of products should include all the essential C4ISR Architecture Framework products. Other C4ISR and non-C4ISR products needed should be defined and the cost estimated.

Table 2. Architecture Development Administration

The cost of initially developing an architecture and its products may be different from sustaining the product once developed. For example, it may take a very experienced person with wide systems knowledge to develop the product or architecture, but a less experienced (perhaps even a more specialized) person or organization to maintain the data currency once the product is in use. The estimated annual personnel cost[2] to administer an architecture development program is provided in Table 2[3]. The annual cost of sustaining the architecture, once developed, is somewhere between 25 and 35% of the initial cost.

Once developed, architectures and architecture products must be made available for use. Traditionally, the process has been to publish paper copies and send them to a list of offices and agencies that are likely to use the information. This process is rapidly becoming obsolete due, primarily, to the need to get current information to a myriad of users in the shortest time possible. The alternative is to host the architecture in a web environment.

The primary advantage to hosting the architecture and its products in the web environment is the speed of access and flexibility in using the products. It is also possible to make almost real-time updates to the architecture instead of waiting for the "next revision" to be published and distributed[4]. The speed, flexibility, and availability of electronic publishing allow architectures to be an active player in the planning and development strategy of an organization.

4.1. Integrating Architectural Methods

The Office of the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (OASD (C3I)) and Joint Staff J6 in conjunction with the CINCs, Services, and Agencies has established a set of architectures which are designed to provide a coordinated architecture design approach [OSD Letter, 1998]. This approach ensures a common denominator for understanding, comparing, contrasting, and integrating architectures across the DOD. This has been promulgated in the form of the C4ISR Architecture Framework. This document, currently in Version 2.0, standardizes architectures to three views: Operational, Systems, and Technical [C4ISR Framework, 1997]. The Architecture Framework also contains a general outline of the content expected in each of the three types of architectures. Use of the C4ISR Architecture Framework is the directed format for all architectures in the DOD[5].

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[2] All salary costs were calculated using the Defense Finance and Accounting Service Monthly Basic Pay chart, effective 1 Jan 1998, and the U.S. Office of Personnel Management 1998 General Schedule, effective January 1998.

[3] Similar tables have been constructed to define each of the 26 Version 2.0 C4ISR Architecture Framework products and their estimated development costs [Beckner and Norman, 1998].

[4] The long-term cost of publishing in a web environment cost effective when compared to publishing and distributing paper copies.

[5] It is important to understand that the C4ISR Architecture Framework provides direction on how to *describe* architectures, not how to *design or implement a specific architecture*, or how to develop and acquire a system or systems.

The C4ISR Architecture Framework is intended to ensure that the architectures developed by the geographic and functional Unified Commands, military Services, and defense Agencies are interrelateable between and among the organizations' operations, systems, and technical architecture views, and are comparable and integratable across Joint and multi-national organizational boundaries. The C4ISR Architecture Framework supports the warfighter by providing a common framework, definition and methodology for architectures across the DOD. The Framework ensures that DOD C4ISR systems migrate towards compliance with DOD technical architecture guidance. It also provides a comprehensive plan by which in-depth analysis of specific architectural issues that cut across architectures can be identified and resolved

Currently many organizations develop architectures. Establishing the C4ISR Architecture Framework standard definitely makes the understanding and comparison of these architectures easier. Establishing the capability to integrate architectural views within an operational or functional domain, and between functional domains facilitates the integration of needs, processes, and capabilities. The ability to integrate between and across architectures facilitates sound and consistent technical planning decisions and reduces costs. The benefits of integrateable architectures has enhanced planning decisions and is beginning to reap benefits at the joint and multinational level as well as at the Service level. Secondary benefits such as training planners to develop architecture products and the dissemination of the architecture products also greatly benefit from the standardizing effect of this initiative.

4.1.1 *The Zachman Framework*

In "*A Framework for Information Systems Architecture*," John Zachman [1987] identified an easy to comprehend methodology for developing an enterprise information architecture. His framework has become a de facto standard for enterprise architecture design. Zachman's framework is intended to provide a method to control decentralization issues within an organization.

The Zachman framework was one of the first approaches that illustrated the need for separate data, process, and technology architecture views within the concept of an enterprise information architecture. Data flows, business processes, and applied technologies are investigated across the organization (or enterprise), each with an individual orientation while being integrated to portray the whole [Cook, 1996].

The various architectures are simultaneously developed by moving through sequential levels of detail while investigating the nature of the organization. Melissa Cook [1996], in Building Enterprise Information Architectures, compares the Zachman levels of detail and the iterative process used to populate the framework to those employed in designing a house or other physical building. This analogy will later be used to advocate the creation of an IT architecture studio.

The levels of architectural views in the Zachman framework, ranging from the broadest to the most detailed are:

- The Ballpark View
- The Owner's View

- The Designer’s View
- The Builder’s View
- The Detailed Representation
- The Functioning System

For each of these levels, the Zachman framework identifies:

- What data is exchanged
- How the function is performed that handles the data
- Where within the network is the function performed
- Who are the people performing the functions
- When is the function accomplished within the concept of operations
- Why is the function performed, in support of which business goal

Consequently, the Zachman framework is portrayed as a six-by-six matrix. Each of the 36 entries in this matrix, illustrates an architectural product that leads to an integrated enterprise architecture. The Zachman Framework is very useful for placing the planning/definition stages into a conceptual framework. It organizes the architectural development into manageable segments. The framework does not explain how to populate the matrix or how to actually implement the architectures in the enterprise.

4.1.2 *Enterprise Architecture Planning*

Steven Spewak’s Enterprise Architecture Planning (EAP) is a process for defining architectures for the use of information in support of the business and the plan for implementing those architectures [Spewak, 1992]. Key here is the concept of using the results of architecting to identify requirements and plan for the implementation of systems, and their eventual acquisition.

Dr. Spewak contends that “architectures are founded on a functional business model.” Consequently, the EAP approach starts with the identification of the organization’s functions and activities. While interviewing staff to ascertain these functions, the architect also identifies the current systems and technologies at work within the organization. Armed with the knowledge of the existing systems and the functions performed by the staff using these systems, preliminary ‘AS-IS’ operational and systems architecture can be generated.

The next phases of the EAP methodology look at the future environment of the enterprise. A data architecture is developed in which the data entities are determined. These data entities are the categories of information which are exchanged by the nodes/elements of the enterprise. Next, an applications architecture is generated in which the existing and needed software applications or systems are identified. The purpose of the applications architecture is to define the major kinds of applications/systems required to manage the data and support the business of the enterprise. Lastly, the technology architecture is developed. The objective of this architecture is to define the major technologies needed to provide an efficient operational environment. A technology deployment plan is generated illustrating the sequenced insertion of emerging technologies into the systems infrastructure of the enterprise [Spewak, 1992].

Having accomplished an EAP study, the architect has populated the first two rows of the Zachman matrix and as the final product, publishes an Implementation Plan for the implementation of the architectures and acquisition of the applications. With higher management buy-in, the implement plan lies out the roadmap for systems migration within the organization.

4.2. Populating Architectures

It takes an architect to populate an architecture. And it takes a team of architects and a great deal of time to generate an architecture. No one architect can be expected to know the entire breath and depth of the enterprise. Therefore, the IT architect must also rely upon and collect information from a large number of people and organizations from within the enterprise under investigation.

The architect must become infinitely knowledgeable of the enterprise. The concept of operations must be characterized, the operational nodes or elements identified, and the information exchanges between the nodes need to be thoroughly investigated and described. The information and communications systems used by the enterprise must be cataloged and their interfaces delineated. Architectural views of the existing operational and information environment must be generated in order the establish an “AS-IS” baseline or foundation [Beamer and Beckner, 1997].

Next, the architect must become a magician, and look into his or her crystal ball. Actually it is a little more scientific than that, there are existing systems engineering practices and procedures for making engineering estimates and predictions of the future predicated on current operations and situations. In this phase of architecture development, the architect is generating the “TO-BE” architectures. Through review of organization documentation and other literature, interviews and surveys, and business practice studies- the architect can determine the needed operational concept for future operations of the enterprise. This includes optimization of interfaces, identification of needed nodes, and determination of information needlines. The planned operational activities of the future, in turn, allow the architect to postulate the target or “TO-BE” systems infrastructure of the future for the enterprise.

The architect populates the architecture by collecting operational, functional, systems information via a variety of data collection methodologies. These can include, but are not limited to: face-to-face interviews, telephone surveys, written questionnaires and surveys, and review of appropriate documents such as concepts of operations, operations plans, strategic plans, and Air Force Instructions.

The architecture database should be hosted in a tool that provides object oriented relational manipulation of the data, query language searches and sorts, web browser connectivity to the internet, and other data analysis capabilities. A number of such tools are on the commercial market and this is not the place to address the specifics of these products or to indorse one over another. Suffice it to say, the tool must permit the architect the ability to generate and populate both graphical representations of the architectures and supporting textual databases.

5.0 Managing Systems Evolution

No architecture, no matter how good, can accomplish much if it is not *implemented*. To implement anything takes management initiatives, attention to the details necessary for success, and a plan. The first step in the planning process is to define and bound the problem. A set of questions has been developed to assist the architect in satisfying this need. Each question is cross-referenced to the product descriptions in the C4ISR Architecture Framework to assist in understanding the basic aspects that should be considered [Beckner and Norman, 1998].

Architecture Councils are evolving as an effective way to govern and guide the development of architectures across domains. Ideally a council includes expert representation across their domain of interest. The councils established, however, must avoid becoming a forum for discussion without progress. This can be avoided through leadership and membership restricted to individuals who will aggressively pursue their chartered responsibilities. The responsibility for a council's success should lie with the Senior Officer over the Council Chairperson.

An example of how a set of councils could be established is at Figure 3. Councils such as this should be established at a level that will ensure enterprise-wide cognizance and oversight.

Figure 3. Architecture Council Structure

One of the primary responsibilities of an Integrated Enterprise Council would be to ensure that the other councils retain an integrated view of the enterprise and strive for joint force interoperability. To do this the Air Force, for example, would work through the MAJCOM, Base, Agency or Domain System Integration Management Organization (SIMO)[6]. As shown in Figure 3, the organizational SIMO Chairperson would probably serve as the organization representative on the Integrated Enterprise Council. This council could also serve as an overarching Enterprise Configuration Control Board [Beckner and Norman, 1998].

5.1 The Development Process

One of the ways that architectures can be closely correlated is by basing them in the context of a global strategy. Joint Vision 2010 and the Global Engagement Strategy are both intended to provide an operational strategy to exploit the full spectrum of US military operations. The foundation of this strategy includes promoting stability with alliances and coalitions and maintaining a multi-mission capable force that can smoothly transition from peacetime security activities to multi-theater wars. Included in this strategy is the ability of US forces to respond to two overlapping conflicts and asymmetric attacks. The Expeditionary Aerospace Force concept is the Air Force vehicle for accomplishing these goals.

Air Force Policy Directive (AFPD) 10-14, *Modernization Planning*, recognizes the need to continually refine, update, and correct the mission and support objectives and tasks [AFPD 10-14, 1995]. The process by which this is done is called the Modernization Planning Cycle. Modernization Planning follows the timing from AFPD 10-14. The objective is to price, prioritize, and integrate products that could influence the Air Force POM before POM submission. Each MAJCOM uses the AF Manual 1-1 as a guide to establish mission area responsibilities throughout this process [AFM 1-1, 1992].

Air Force Modernization Planning Cycle is designed to support the POM activities by providing the needed status and requirements information to senior Air Force leaders at scheduled decision points such as the Corona Briefings and key presentations such as the Defense Program Guidance (DPG), which directly influence the POM development.

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[6] The concept of a SIMO was adopted and put into use by the DOD Intelligence Information Systems (DODIIS) community. The purpose of the SIMO is to provide a structured methodology to identify and document systems architecture goals. The SIMO also plans cost-effective, operationally focused implementation of these goals; monitors the status of critical activities associated with the plan; executes the transition from existing to desired baselines; and communicate results of analysis, transition status, issues, and resolution plans, and makes recommendations to senior management. The DODIIS SIMO program has been very successful and is used widely by various DOD Unified and Specified Commands, MAJCOMs, and Agencies. The SIMO concept provides a forum for feedback for operators, planning and verification for maintainers, schedules and status for developers, C2 plans and requirements for warfighters, security guidance for information systems security managers, project plans, schedules and status for project action officers and commitment from senior managers. The process provides a needed interface in a structured manner to insure that all aspects of systems development—from inception to retirement—are understood. From this forum come consolidated understandings and courses of action.

The POM is a biennial memorandum submitted by the Secretary of Defense (SecDef) from each Military Department and Defense agency. Each POM proposes total program requirements for the next six years. Included in the submission is the rationale for planned changes from the approved Future Years Defense Program (FYDP) baseline within SecDef fiscal guidance.

The process starts in the "Out of Cycle (with the POM) Year" with the Mission Area Assessment (MAA). The MAA refines the guidance provided by Headquarters USAF in the Air Force Strategic Plan. The next step, the Mission Needs Analysis (MNA), refines task to need. Here the MAJCOMs analyze the force structure, geopolitical environments, projected advances in technology, interoperability concerns, and expected threats affecting their current and programmed capabilities to accomplish a task. From this analysis deficiencies in current and future capabilities are identified. A Mission Need Statement (MNS) is then developed to document specific materiel deficiencies that the MAJCOMs cannot correct through non-materiel solutions such as adjusting doctrine, tactics, and training. An Operational Requirements Document (ORD) is usually associated with the MNS. The ORD identifies the operational requirements necessary to meet the identified need. All Air Force ORDs must be accompanied by a Requirements Correlation Matrix (RCM). The RCM is a matrix spreadsheet outlining the user's operational requirements in terms of capabilities and characteristics.

A Mission Area Plan (MAP) is the primary product of the Air Force POM process. MAPs cover periods of 25 years and use the products of the MAA and MNA to document the most cost-effective corrections of task deficiencies. A MAP is comprised of individual weapon's system/capability roadmaps with a modernization plan and descriptions of enabling technologies that can be expected to correct the task deficiencies. Air Force functional areas such as command, control, communications, and computers, security police, intelligence, or civil engineering, may develop similar plans called a Mission Support Plan (MSP) to serve this same purpose.

The MAP and its supporting equivalent, the MSP, identify the *strategy* necessary to achieve goals. The actual development and evolution of systems and capabilities, however, is governed largely through technically oriented details contained in documents such as the MNS and ORD.

MAJCOMs integrate MAPs and MSPs to provide the fiscal prioritization across their areas of responsibility[7]. The integration must be sufficiently detailed to support Air Force modernization planning through the Biennial PPBS cycle. The MAJCOMs also coordinate with supported CINCs to prioritize Research, Development, and Acquisition (RD&A) programs to support the MAPs.

Committees of senior Air Force leaders (i.e., the AF Group, Board, and Council) review the MAJCOM program lists and any associated funding disconnects with fiscal limits that MAJCOMs cannot resolve. The committees reprioritize programs if necessary and recommends for the Chief of Staff's approval corrections of task deficiencies that meet fiscal constraints.

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[7] MAJCOMs may request Theater CINC/Component Commander inputs prior to MAA completion and can include functional area (e.g., intelligence) and mission support area considerations in their MAPs. HQ AFMC supports the preparation of MAAs, MNAs, and MAPs/MSPs through Technical Planning Integrated Product Teams. The ACISRC coordinates C2 MAP across the Air Force.

The Chairman of the Joint Chiefs of Staff (CJCS), in consultation with the other members of the Joint Chiefs of Staff and the combatant commanders, also has an input to the process of developing the overall budget for military expenditures. The objective of the CJCS input is to ensure that strategic plans and direction for the Armed Forces are consistent and will interact in a positive manner with all other DOD systems. The JSPS is the formal process used by the CJCS for reviewing the national security environment and US national security objectives, threat evaluation, assessment of current strategy, existing and proposed budgets, and the programs and forces necessary to achieve all national objectives. Taken together, the JSPS and the PPBS have a combined purpose of furnishing the best possible mix of missions, forces, equipment, and support to the combatant commanders [AFPD 10-14].

5.2 Implementing the Architecture

Clearly the magnitude of the architecture and planning activity across an organization should be simplified and standardized to the greatest degree possible. This is necessary to make architectures understandable, compatible, integratable, and not redundant, overlapping, or unnecessary. There also needs to be a top-level view of the enterprise. The top-level view should reflect the substance of the common infrastructure and the ability to interoperate with the other organizations (Services and Agencies), and allies.

An example of the evolution to the concept is shown in Figure 4. As can be seen, a seamless and integrated view of the nodes and connectivity within and between nodes and systems is highly desirable. To succeed the integrated architecture should also be an evolving and forward-looking architecture—one that can be referenced to determine the course of evolution of systems and capabilities. To be effective *the* repository of enterprise-wide connectivity and interoperability should reside in a widely accessible media such as a web environment. The database should reflect the current systems and structure plus the vision of the future. The future vision should be time-phased and contain the needs, programs and schedules in effect. All known issues, including those dealing with funding should also be resident and available for access, review, resolution, and update. The focus should be on the information systems that make up the command and control systems. The emphasis should be on developing the commonality between systems and capabilities that will result in a common robust information infrastructure with tentacles to specific mission systems and needs [Spewak, 1992].

One of the primary purposes in generating architectures should be to support the acquisition process. Operational architectures define user needs in terms of what is needed (capabilities/ activities and information/data models), where it is needed (nodes), who needs the information (information exchanges), and how to provide information system capabilities to support the users (operational activity to system function traceability matrix), and other systems architecture products. A time-phased approach to implementing the information system capabilities is provided by defining the current and projected operational architecture products and defining the system evolution to meet these needs over time. As previously indicated, the systems evolution description can be the foundation of the information technology budget (and defined in the information technology portion of the POM).

Figure 4. Integrated Architecture Evolution

5.3 Building Capabilities

Figure 5 highlights the system engineering activities needed to develop capabilities within the Air Force. The systems architecture plays a key role in each of these steps from requirement correlation to fielding of capabilities at the architectural nodes that apply.

The return arrow in Figure 5 emphasizes the beneficial tie between the architecture update cycle and the formal Air Force Modernization Planning Cycle. This tie allows updated products to be available for use during the annual Air Force PPBS and POM activities.

The Air Force Modernization Planning process should also benefit from several recent initiatives that focus on capabilities planning and development. These include the initiative to conduct annual “live fly” Expeditionary Force Experiments (EFX). The objective of the EFX-series experiments is to identify technologies and capabilities that should rapidly be assimilated into the warfighters weapons inventory. The “Live Fly” experiments test the capabilities developed in a realistic manner with the warfighter involved to the maximum extent. If there are changes or modifications needed, they will be identified here. If not, the capability is manufactured and fielded in the shortest time possible. To complement this objective acquisition agencies are now focusing on a spiral development cycle needed to continue their work.

Figure 5. Core Implementation Process

Architecture views are being used to support EFX execution and spiral development evolution. The C4ISR Architecture Framework provides the means for accurate and equitable comparisons between domain architectures within the Air Force and across the DOD to support a consolidated, architecture-based modernization process.

Figure 6 is an overview of the traditional Air Force development process starting with what is needed militarily as stated in policy, assigned mission tasks, strategy and other initiatives. The command planning found in architectures, CONOPs, and various Master Plans establish the priorities for accomplishing what is needed. The acquisition community responds to the command planning with analyses, MNS, ORD, and other development programs. Those to be evolved become part of the Spiral Development process. These are developed and validated in a realistic unified command and control battlespace environment and at battle laboratories. When

Figure 6. The Planning Process

they will be provided to the warfighter is reasonably predictable due to the goals and controls of the Spiral Development process. Programs which do not build upon existing systems usually enter the development process through the development of a Statement of Work (SOW) and specifications. The SOW/Specification methodology is becoming less predominant than in past years, mostly due to the shortage of funds to start "new" developments, and because the emphasis on the DII COE and other initiatives designed to build on COTS products and evolve capabilities instead of developing unique military systems[8].

Ensuring that evolution, by the spiral development methodology, benefits from the leading edge of competent technology is extremely important to the successful use of the developed capability by the warfighter. The step of infusing technology into the process must be considered and successfully implemented. The simultaneous application of agreed upon standards is also critical to joint interoperability goals and requirements.

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8 An understanding of how the overall process works is important to defending funding expenditures. A challenged program of capabilities at the lowest level should be able to trace its origin back to some requirement higher in the process, and ultimately to National Policy. If a level of the planning process has been bypassed, or some key document is missing or does not exist, e.g., an operational architecture, then justifying the development may be in jeopardy.

5.4 Spiral Development

The Spiral Development process depicted in Figure 7 is focused on rapid, thorough, and continuous evolution of capabilities for the warfighter. The thrust of the concept is guided by the Systems and Technical Architecture products and the needs expressed in the mission area and mission needs analyses that are part of the POM process. The Spiral Development process has set a goal of completing one cycle of capability development, testing, evaluating, and training within a notional 18-month period. At the end of each 18-month cycle capabilities identified in

Figure 7. Spiral Development

the Evolution Plan should be available for use in the field, and would be deployed immediately upon operator approval without an interruption in service or the requirement to operate both the "old" system and the "new/upgraded" system at the same time. Simultaneously, the cycle continues with added technologies, user feedback, Defense Advanced Research Projects Agency and battle laboratory technology insertions, and in-house analysis[9]. The cycles continue toward

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9 The Spiral Development Team should maintain contact with the battle laboratories and agencies doing research and testing. The development team is in the position to know that a system or capability is in the evolution process. Once the contact has been made, it is the responsibility of all parties to ensure that an atmosphere of coordination, cooperation, and mutually beneficial exchange of information is maintained.

goals set by the Operational Architectures and the DPG. Using this process the capabilities provided for each operational and functional domain would continuously be improved and new capabilities would be fielded much more quickly and at less cost than by the traditional methods used in the past.

5.5 An Architectural Example

The authors have been involved with several information technology architecture development efforts during the past decade. One project warrants description in this paper as it employed precepts and methods extracted from several architectural approaches. The project was called the Headquarters Air Force (HAF) Information Architecture Planning (IAP) Study and followed the basic tenets of Steven Spewak's Enterprise Architecture Planning (EAP) approach.

Staff were selected from each of the Deputy Chief of Staff (DCS) organizations from within the Headquarters Air Force to study the HAF information infrastructure and develop an architecture implementation plan. One or two representatives from each DCS were assigned to the HAF IAP Core Team. The Core Team functioned for thirteen months (5 Jan 98 to 1 Feb 99) with members participating for as short as two months or, as in most cases, the entire duration of the study. Membership on the Core Team was determined both by the skill mixed and experience/background needed on the team during particular phases of the study and by availability of personnel being released from their regular duties within the various DCS.

As the HAF IAP Core Team developed the Enterprise Architecture Implementation Plan, an oversight committee was established called the Reference Group. This group consisted of 0-6 (full colonel) or equivalent members, once again, representing each of the DCS organizations within Headquarters Air Force. The Reference Group met monthly, on a regular basis, and also 'as needed' to review specific products of the Core Team before these products were eventually presented to an executive steering group.

For this study, the role of the executive steering group was performed by the Air Force Chief Information Officer's (CIO) Management Board (MB). The board consists of the Air Force CIO, the Deputy CIO, the Assistant Vice Chief of Staff of the Air Force, and the Deputy Chiefs of Staff from a number of the DCS organizations such as, but not limited to: SAF/AQ, AF/SC, SAF/FM, AF/IL, AF/XO, AF/XP, and AF/RE. The AF CIO MB empowered the HAF IAP Core Team with access throughout the Headquarters within the Pentagon and granted authority for the Team to conduct interviews and distribute questionnaires and surveys as needed in order to perform their studies.

In essence, the HAF IAP Core Team constituted a team of architects working in an Architecture Studio. The Core Team was provided a separate, secluded facility in which to meet on a daily basis and to conduct its operations. Core Team members supported the HAF IAP effort full time during their tenure on the team and reported to the team facility for duty. The team was physically located within walking distance to the Pentagon.

Initially, all Core Team and some Reference Group members were trained in the Spewak EAP methodology. This consisted of a one week formal seminar (conducted twice, Jan 98 and July

98) and periodic "just in time" training sessions before each subsequent phase of the study. Two or three Spewak, Inc. associates facilitated the Core Team activities at all time throughout the thirteen month effort.

The goal was to populate the first two rows of the John Zachman Framework matrix by employing Steven Spewak's EAP processes for the enterprise of the Headquarters Air Force. The final product of a Spewak EAP study is an Implementation Plan for the Enterprise Architecture that is developed and a prioritized set of projects or applications to be acquired to attack the information deficiencies of the organization and fill information management gaps.

The first step was to develop a set of information management principles or first tenets to guide the entire effort and to be adapted by the enterprise (Headquarters Air Force) as a whole. The Core Team generated a set of 17 principles, which were approved by the AF CIO MB in July of 1998. In parallel with principle development, the team set to work generating a business model of all the activities and tasks performed in the HAF. Eventually, after months of study and intensive interviewing and surveying, a business model of 238 functions was produced. For each function, the team ascertained which organization was responsible for the function, why it was performed, which mission was supported, the inputs and outputs to the activity, which systems were employed, and several other characteristics of the function.

A subgroup of the IAP Core Team, also in parallel with the above efforts, started the Current Systems and Technology phase of the Spewak EAP methodology. This team collected information on the existing automated information systems (AIS) that are used within the HAF. These are the systems that are employed to perform the functions that are delineated in the business model. Also, collected were the information technologies that are inherent in the systems. The team published an Information Resource Catalog (IRC) of the nearly 250 systems used by the staff of the Headquarters Air Force.

With a business model of the HAF established, a catalog of existing systems and a listing of utilized technologies captured in an Access database, the team could begin to construct parts of both an "AS-IS" Operational and Systems Architecture based upon the guidance in the DoD C4ISR Architecture Framework document. An Operational Concept graphic was generated, a node-to-node connectivity diagram was drafted, an information exchange matrix was populated, activity trees were generated, organization charts printed, and a logical data model created as parts of an "AS-IS" Operational Architecture.

Then the Core Team turned its attention to developing data, application, and technology blueprints for the future information needs of the HAF. During the interview and survey phase of the effort, the team collected data on deficiencies, disconnects, information flow needs, opportunities for improvements, and other gaps in the functioning of the headquarters. Using Spewak EAP techniques, the team analyzed the collected data and generated: data entities for the HAF, a list of needed "TO-BE" applications, technology deployment plans, technology position statements, and a set of prioritized capability improvement projects (CIPs).

The final product of the effort, The Implementation Plan, delineated the acquisition strategy for the prioritized CIPs. The plan illustrated a time phased implementation schedule for the acquisition and integration of the CIPs into the HAF information environment. Staff from the Air Force's Electronic Systems Center was enlisted as part of the effort to facilitate integration of the capability improvement projects and to acquire new applications, as applicable.

Most recently, in February of 1999, the IAP EAP effort was subsumed into a newly formed organization, with the charter to oversee and act as a central point of contact for information management, information systems acquisition, and general information operations for the Headquarters Air Force. This organization was named the Headquarters Information Planning Program Office (HIPPO) and is administratively part of SAF/AA (Secretary of the Air Force, Administrative Assistant).

Thus, the HAP IAP was one of the first efforts to utilize a structured enterprise architecture methodology, sequester a team of "architects", analyze an enterprise, generate architectures, delineate solutions in the form of capability improvement projects, and actually begin the process of acquisition through the spiral development approach of the Electronic Systems Center (ESC).

6.0 Conclusions

The tools and techniques provided in the C4ISR Architecture Framework are designed to put products, programs, capabilities, activities, relationships and applications in a context that streamlines analysis and integrates visions and knowledge in a common format that can be used efficiently by planners and decision makers. The power of the C4ISR concept lies in its compliance with Federal mandates and its use throughout the DOD. Using architecture products to complement and strengthen the Air Force modernization planning and POM process is basic to good management of resources.

The facility where operations, planning, architectures, and development decisions come together is the Architecture Studio. Architecture Studios are in being and are being used to define and plan complex systems for warfighting CINCs. Once the plan has been established in the architecture studio, it is ready for the Spiral Development process and implementation. The architecture studio never closes. It continues to monitor, record, and guide the evolutionary steps of the Spiral Development process. By doing this, it is always ready and available to do replanning based on suddenly appearing operational requirements or fiscal changes.

The Spiral Development process usually functions as a continuous process. A good example is the recent Air force initiative to treat Command and Control as an overarching capability instead of an adjunct to stovepiped systems. This initiative was a major step in the unifying of the Air Force portion of the DOD Force structure. From this basis has grown the consolidation of thought and effort that has resulted in a more consistent global view of capabilities. This view stresses how Commercial off the Shelf (COTS) products, guided by common information communications and operating environment, and joint architecture management councils, can develop, produce, and field capabilities that capture Joint Vision 2010 goals.

Injecting the results of the spiral development process into the fiscal modernization equation is a highly desirable technique that could benefit the funding of developing systems and capabilities. Use of the development information provided by the spiral development process could clearly indicate what the latest technology has produced or is about to produce. This knowledge should be invaluable to guiding supplemental development programs that will take full advantage of current technology and developments and linking them to the POM process.

Getting feedback from the warfighter and the activities of the battle laboratories into architectures is vital. There must be continuous dialog between the CINCs, Services, Component Commands, Agencies, and architecture-OPLAN developers. The responsibility for this process lies at the Joint and Service organizations. This, however, does not relieve the field commands and agencies from their responsibilities to coordinate and disseminate information of mutual interest.

The key to successful evolution strategy for subsystems and capabilities is updating selected management processes. What needs to be done is to migrate from “stove pipe” engineering and development to council-based engineering. Likewise there needs to be a migration from myopic systems analysis and capabilities definition to DOD-centric developments and decisions which focus on integrated, joint, and in some cases multinational, engineering. Inherent in the Spiral Development concept are requirements for redefining the management processes to consolidate program budgeting along the lines of specific, approved capability sets. To efficiently achieve the goals established for the next century, the POM process needs to be amended to accommodate the evolving changes in the management processes.

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Glossary

AFPD	Air Force Policy Document
AIS	Automated Information System
APPG	Annual Planning and Programming Guidance
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CIO	Chief Information Officer
CIP	Capability Improvement Project
CJCS	Chairman of the Joint Chiefs of Staff
COTS	Commercial off the Shelf
DCS	Deputy Chief of Staff
DII COE	Defense Information Infrastructure Common Operating Environment

DoD	Department of Defense
DODIIS	DoD Intelligence Information Systems
DPG	Defense Program Guidance
EAP	Enterprise Architecture Planning
EFX	Expeditionary Force Experiments
ESC	Electronic Systems Center
FYDP	Future Year Defense Program
GPRA	Government Performance and Results Act
HAF	Headquarters Air Force
HIPPO	Headquarters Information Planning Program Office
IAP	Information Architecture Planning
IRC	Information Resource Catalog
IT	Information Technology
MAA	Mission Area Assessment
MAJCOM	Major Command
MAP	Mission Area Plan
MB	Management Board
MNA	Mission Needs Analysis
MNS	Mission Need Statement
MPP	Modernization Planning Process
MSP	Mission Support Plan
OASD	Office of the Assistant Secretary of Defense
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
PB	President's Budget
POM	Program Objective Memorandum
PPBS	Planning Programming and Budgeting System
RCM	Requirements Correlation Matrix
RD&A	Research, Development, and Acquisition
SIMO	System Integration Management Organization
STT	Strategies-to-Task